REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
01-05-2008	Final report	01-APR-05 to 30-SEP-07

4. TITLE AND SUBTITLE

Internal Mass Motion for Spacecraft Dynamics and Control

5a. CONTRACT NUMBER

FA9550-1-0217

5b. GRANT NUMBER

FA9550-1-0217

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AF OFFICE OF SCIENTIFIC RESEARCH
875 NORTH RANDOLPH STREET ROOM 3112
ARLINGTON VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

AFRL-SR-AR-TR-08-0265

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A: UNLIMITED

13. SUPPLEMENTARY NOTES

14. ABSTRACT

We present a detailed description of the application of a noncanonical Hamiltonian formulation to the modeling, analysis, and simulation of the dynamics of gyrostat spacecraft with internal mass motion. The methods have been applied to the practical implementation of control of a three-dimensional air bearing spacecraft simulator. We also present the analysis of electrodynamic tether systems, including optimal control of a simplified model.

15. SUBJECT TERMS

spacecraft dynamics control Hamiltonian simulator air-bearing electrodynamic tether optimization

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Christopher D. Hall
					19b. TELEPHONE NUMBER *(Include area code)* 540 231 2314

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Final Report

Project Title:	Internal Mass Motion for Spacecraft Dynamics and Control
Contract Number:	FA9550-05-0217
Period:	April 2005 – September 2007
Submitted By:	Christopher D. Hall Department of Aerospace and Ocean Engineering Virginia Polytechnic Institute and State University Blacksburg, VA 24061 (540) 231-2314 (540) 231-9632 (FAX) cdhall@vt.edu
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Summary

In this project, we have investigated a variety of problems arising in the orbital and attitude dynamics and control of spacecraft with internal mass motion, as well as in the modeling and simulation of electrodynamic tether spacecraft systems.

Accomplishments/New Findings

Our primary accomplishments include the development of simulation and visualization tools for controlling of spacecraft simulators with a variety of sensors and actuators. The Distributed Spacecraft Attitude Control System Simulator (DSACSS) facility, housed in the Space Systems Simulation Laboratory (SSSL) at Virginia Tech provides a high-fidelity solution for Earth-based real-time hardware-in-the-loop simulations of space vehicles. DSACSS allows individual and component level development and testing of hardware and software interfaces. DSACSS is comprised of two hardware simulators and one software spacecraft simulator mounted on separate platforms that allow the ability to demonstrate decentralized control algorithms. The two hardware simulators are mounted on individual spherical air bearing platforms, which allow only for rotational motion. The two hardware simulators have different configurations and consequently a different amount of rotational freedom. The third simulator is comprised of software running on a flight computer.

Additional work conducted during this grant period included investigation of the modeling and simulation, and optimal control of, electrodynamic tether systems, as well as the development of a new relative motion theory for satellite constellations and formations.

Personnel Supported

In addition to the Principal Investigator, several graduate students, undergraduate students, and one post-doctoral associate have participated in related research. Scott Kowalchuk completed his PhD in 2007 and is currently with Analytical Mechanics Associates in Hampton, Virginia. Mischa Kim completed his PhD and is currently with Embry-Riddle Aeronautical University in Prescott, Arizona. Current PhD advisees are Carmen Catacora (NSF Fellow), Joshua Ellis (NDSEG Fellow), Soung Sub Lee (Korean Air Force officer), and Matthew Van Dyke (with Orbital Sciences Corporation). Current M.S. advisees are Matthew Bitzer, John Dolan, Tim Janezic, and Brian Williams.

Publications (* indicates student) All publications are available as pdf documents linked from the PI's website: http://www.aoe.vt.edu/~cdhall

Refereed journal articles since 2005:

1. R. A. Sandfry* and C. D. Hall, "Bifurcations of Relative Equilibria of an Oblate Gyrostat with a Discrete Damper," Nonlinear Dynamics, Vol. 48, No. 3, 2007, pp. 319–329

2. M. Kim* and C. D. Hall, "Dynamics and Control of Tethered Satellite Systems," Journal of Spacecraft and Rockets, Vol. 44, No. 3, 2007, pp. 649–659

3. C. D. Hall and J. A. Beck, "Hamiltonian Mechanics and Relative Equilibria of Orbiting Gyrostats," Journal of the Astronautical Sciences, Vol. 55, No. 1, 2007, pp. 53–65

4. H. Schaub, C. D. Hall, and J. Berryman*, "Necessary Conditions for Circularly-Restricted Static Coulomb Formations," Journal of the Astronautical Sciences, Vol. 54, Nos. 3–4, 2006, pp. 525–541

5. M. C. VanDyke* and C. D. Hall, "Decentralized Coordinated Attitude Control of a Formation of Spacecraft," Journal of Guidance, Control, and Dynamics, Vol. 29, No. 5, 2006, pp. 1101–1109

6. M. Kim* and C. D. Hall, "Symmetries in the Optimal Control of Solar Sail Spacecraft," Celestial Mechanics and Dynamical Astronomy, Vol. 92, No. 4, 2005, pp. 273–293

Conference papers since 2004:

1. S. A. Kowalchuk* and C. D. Hall, "Spacecraft Attitude Sliding Mode Controller using Reaction Wheels," 2008 AIAA/AAS Astrodynamics Specialists Conference, Honolulu, Hawaii, August 2008

2. S. S. Lee* and C. D. Hall, "Geometrical Relative Orbit Modeling of Satellite Relative Motion," F. Landis Markley Astronautics Symposium, Cambridge, Maryland, June 2008

3. J. E. Ellis* and C. D. Hall, "Numerical Model Development and Verification for the Dynamics of an Electrodynamic Tether System," 2008 AAS/AIAA Space Flight Mechanics Meeting, Galveston, Texas, January 2008 (John V. Breakwell Student Travel Award)

4. M. S. Bitzer* and C. D. Hall, "Optimal Electrodynamic Tether Phasing Maneuvers," International Symposium on Space Flight Dynamics (ISSFD), Annapolis, Maryland, September 2007

5. M. S. Bitzer* and C. D. Hall, "Optimal Electrodynamic Tether Phasing Maneuvers," Virginia Space Grant Consortium Student Conference, Hampton, Virginia, April 2007

6. J. E. Ellis* and C. D. Hall, "Dynamics of an Electrodynamic Tether System Including Gyrostat End Bodies," 2007 AAS/AIAA Space Flight Mechanics Meeting, Sedona, Arizona, February 2007

7. S. A. Kowalchuk* and C. D. Hall, "GPS Hardware-in-the-loop Spacecraft Formation Flying Simulation," 2007 AAS/AIAA Space Flight Mechanics Meeting, Sedona, Arizona, February 2007

8. S. A. Kowalchuk* and C. D. Hall, "Hardware-in-the-Loop Simulation of Classical Element Feedback Controller," Flight Mechanics Symposium, NASA Goddard Space Flight Center, Greenbelt, Maryland, October 2005

9. S. A. Kowalchuk* and C. D. Hall, "Distributed Spacecraft Attitude Control System Simulator Feedback Control Capabilities and Visualization Techniques," 7th International Symposium on Quantitative Feedback Theory (QFT) and Robust Frequency Domain Design Methods, University of Kansas, August 2005

10. H. Schaub and C. D. Hall, "Static Coulomb Formation Necessary Conditions," Malcolm Shuster Symposium, Buffalo, New York, June 2005

Theses:

Scott A. Kowalchuk, Ph.D., *Investigation of Nonlinear Control Strategies Using GPS Simulator and Spacecraft Attitude Control Simulator*, September 2007. Virginia Space Grant Fellow. Currently with Analytical Mechanics Associates, Hampton, Virginia

Mischa Kim, Ph.D., *Continuous Low-Thrust Trajectory Optimization*, May 2005. Currently Assistant Professor, Embry-Riddle Aeronautical University, Prescott, Arizona. Paul E. Torgersen Research Award Winner